Sustainable management of transboundary river basins: a line of reasoning

Lorenz, C.M.; Gilbert, A.J.; Vellinga, P.

published in
Regional Environmental Change
2002

DOI (link to publisher)
10.1007/s101130100023

document version
Publisher's PDF, also known as Version of record

citation for published version (APA)
Lorenz, C. M., Gilbert, A. J., & Vellinga, P. (2002). Sustainable management of transboundary river basins: a line of reasoning. *Regional Environmental Change*, *2*, 38-53. https://doi.org/10.1007/s101130100023

Sustainable management of transboundary river basins: a line of reasoning

C.M. Lorenz · A.J. Gilbert · P. Vellinga

Abstract This paper identifies a line of reasoning based on a number of concepts and tools to facilitate river basin management, which have been applied in a case study. For long-term sustainable river basin management, a balance is needed between the human use of the river and its basin, the ecological functioning of the river and receiving waters, and the river's capacity to supply goods and services. To find such a balance a framework is needed that illustrates and clarifies possible trade-offs between economic use and environmental supply by integrating scientific information on cause–effect chains on a catchment scale. A number of concepts and tools are proposed as a basis for this framework. The tools are: (1) indicators that describe the complex interactions and processes in rivers; (2) a suite of linked models that predict the economic, environmental and ecological effect of management measures; (3) an evaluation framework to rank different management alternatives on the basis of three objectives: economic efficiency, spatial equity in costs and benefits and environmental quality of the river and receiving lakes. The concept of environmental quality defines the potential of the river environment (i.e. natural capital) to contribute to human welfare. The concept of environmental functions is used to identify societal interest in natural capital. The concept and tools have been applied in a case study involving the evaluation of four management strategies on nutrient abatement in the Rhine basin. The result of the case study is that economic efficiency is in conflict with spatial equity and environmental quality. Spatial equity is in agreement with environmental quality.

Keywords Sustainable development · River basin management · Case study · Rhine · Indicators · Economy–ecology

Received: 10 September 1999 / Accepted: 9 March 2001
Published online first: 21 June 2001

C.M. Lorenz (✉)
Witteveen and Bos Consulting Engineers, Van Twickelostraat 2, 7411SC Deventer, The Netherlands
e-mail: c.lorenz@witbo.nl
Tel.: +31-570-697911
Fax: +31-570-697344

A.J. Gilbert · P. Vellinga
Institute for Environmental Studies, De Boelelaan 1115, 1081HV Amsterdam, The Netherlands

Introduction

During the last decade, transboundary river basin management in Western Europe has been triggered by environmental or socio-economic calamities. Consider the Rhine Action Plan (Internationale Kommission zum Schutze des Rheins 1987), stemming from the Sandoz calamity. A fire at the pesticide-producing plant Sandoz in Basle, Switzerland, in 1986 caused a massive fish kill. The agreement of Arles on flood protection (Internationale Kommission zum Schutze des Rheins 1995) was reached after the floods of the River Rhine in 1994 and 1995. The floods led to a large-scale evacuation of the population living along the Rhine in The Netherlands. The development of the Grensmaas project (Projectbureau Grensmaas 1994) started after the Meuse floods in 1993 and 1995. Despite being disaster-driven, these agreements and plans respond to perceived needs for an integrated approach to management, one that takes multifunctional use explicitly into account at the catchment scale. In the Rhine Action Plan (Internationale Kommission zum Schutze des Rheins 1987) the Rhine riparian states committed themselves to further reductions of discharges of priority pollutants, aiming at ecological rehabilitation, safe drinking water production and prevention of sediment pollution, and protection of the North Sea. The agreement of Arles aims to combine flood protection with ecological restoration. The project Grensmaas is a comprehensive plan to widen the river bed with the aim of enabling flood protection, nature development and mineral extraction, all at the same time.
In the same year as the agreement of the Rhine Action Program, the World Commission on Environment and Development introduced the concept of sustainable development (World Commission on Environment and

 DOI. 10.1007/s101130100023

Development 1987). Since then this concept has been accepted by a large number of countries as a guiding principle for their long-term environmental, economic and social policies. Still, most countries and river authorities struggle with its operation and implementation. Integrated river basin management, aiming at the integration of economic use of the river, ecosystem functioning and international and institutional aspects, can be seen as a policy process towards sustainable development. Transboundary rivers offer even more challenges for this process, because the crossing of administrative borders makes management responsibilities less clear and the processes of negotiation and decision-making more complicated.
The aim of this paper is to specify what management for sustainable development can mean in the context of transboundary river basins and to derive a number of tools and concepts to facilitate this management. The identified concepts and tools have been applied to a case study on nutrient reduction in the Rhine basin.
We focus in this paper on Western European transboundary rivers, as they offer good conditions for a sustainability assessment. Western Europe has a stable and co-operative political environment with a relatively high degree of welfare. Furthermore, the stakeholders are organized in supra-national organizations, such as the European Union and such international committees as the International Rhine Commission. With regard to transboundary aspects, European large rivers cross a number of different countries having a different cultural background and different political systems (for example, compare the federal political system in Germany with the centralized system in The Netherlands and France). This increases the complexity of transboundary river management.
The paper consists of the following sections:

1. The concept of sustainable development.
2. Socio-economic use and ecological feedbacks in transboundary rivers.
3. Concepts and tools for sustainable management of transboundary rivers.
4. Application of concepts and tools to a case study.
5. Discussion and conclusions.

Sustainable development: definitions, capital theory and views on nature

The concept of sustainability was first used to define the physical limits to the exploitation of individual resources, especially of forests and fish stocks (Braat 1992). The concept of sustainability, as it is now used, grew out of the "Limits to growth" debate of the early 1970s (Meadows et al. 1972; Cole et al. 1973), which discussed whether or not continuing economic growth would lead to severe environmental degradation and social collapse on a global scale. The World Commission on Environment and Development stated that economic development could be compatible with the solution of the environmental problems, provided that it took place in a sustainable way (World Commission on Environment and Development 1987). Their definition – "...the development that meets the needs of the present without compromising the ability of future generations to meet their own needs" – while not very specific, has been widely accepted and a number of governments have taken the concept of sustainability as a guiding principle for the development of their environmental, economic and social policies (e.g. Germany, the United States, The Netherlands). Despite the initial enthusiasm, some disappointment appeared later because the concept provides no direction for management and no readily identifiable means of achieving the desired end. Sustainable development is better seen as a framework that assists the harmonization of disparate interests (e.g. Verbruggen 1995).
A number of authors (Daly 1974; Solow 1974; Hartwick 1977; Pearce and Turner 1990; Serageldin and Steer 1994) have applied the capital theory from economics to environmental problems and the concept of sustainable development. This has led to the definition of four types of capital:

1. Natural capital (stock of environmental assets providing a flow of goods and services).
2. Human-made capital (fabricated capital such as machines, factories, buildings).
3. Human capital (e.g. labour, skills and other products of investment in education, health, etc.).
4. Social capital (e.g. the institutional and cultural basis of a society).

Flows between these capitals will change the amount of each capital, for example the production of economic goods from non-renewable natural resources will increase human-made capital and decrease natural capital. In that case natural capital is substituted by human-made capital. Flows between capitals can also lead to a change in total capital. In Fig. 1 the four types of capital and flows between them are illustrated in a river context.
Serageldin and Steer (1994) specified a minimum condition for sustainable development: the total amount of capital (the sum of 1–4 above) in a society should be non-declining at any time. Assumptions regarding substitutability among the different types of capital, meaning that one type of capital is substituted into another type of capital, lead to a spectrum of possible sustainable states. At one end of this spectrum lies weak sustainability, where there are no constraints to substitutability of capital, in particular natural capital. At the other end is strong sustainability, where substitutability of natural capital into another type of capital is either not possible or at least severely constrained. Between these two extremes lies a spectrum that is defined by (at least) two issues: life support and complementarity among capitals. The natural capital needed to maintain life-support services essential to human survival (e.g. biochemical cycling, space) is called critical natural capital and cannot be substituted. Those supportive of the strong sustain-

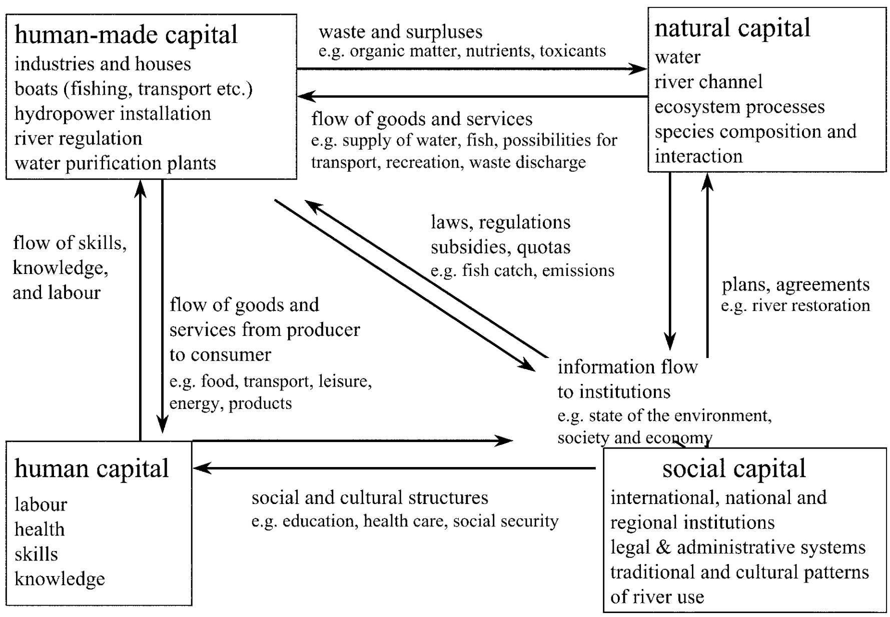

Fig. 1
Overview of interactions among the four types of capital, elaborated for a river context

ability perspective advocate the precautionary principle with regard to substitution. This means that the uncertainty with regard to the amount of natural capital critical for human survival and the risk of irreversible environmental impacts does not allow a further decline of natural capital (Turner et al. 1993). The precautionary principle is not a panacea (i.e. it has costs implicated), but it is a rational risk-averse strategy in contexts of systematic uncertainty (Freestone and Hey 1996; Commission on the European Communities 2000).

The principle of complementarity (Turner et al. 1993) focuses on mutual dependencies among different capitals, rather than on the capacity of one to replace another. For example, commercial fishing involves interaction among human-made (boats and equipment within the fleet), human (labour, skills and knowledge, often culturally bound) and natural (the fish stocks themselves, and their abiotic and biotic requirements, such as spawning grounds, water and sediment quality and food resources) capitals in the context of a set of institutions (social capital for the setting of quotas and subsidies). A decline in the natural capital fish will have negative effects on the other capitals, such as labour and income in the short term and knowledge and skills in the long term.

The capital theory has the advantage that it takes into account economic, ecological and social values at the same time. It focuses attention on trade-offs between interests associated with nature, economy and society. It is likely that there are minimum stocks of each of the individual components needed for development to be sustainable. The minimum aggregate condition for sustainability does not address this issue. The question of the exchange rate among capitals also remains.

The sustainability debate clearly shows the need for a framework within which the interests associated with nature, economy and society can be traded-off (see also Van Rooy and De Jong 1995). The approach taken to operationalize sustainability in this study focuses on providing information on relationships and interactions between the river and its socio-economic environment, instead of searching for scientifically determined sustainability thresholds. The reasons for this choice are: (1) the difficulty of defining scientifically determined sustainability thresholds, especially for large and complex systems such as large rivers; and (2) once a sustainability level is defined from a disciplinary point of view (e.g. economic, societal or environmental), it runs a high risk of being incompatible with the sustainability levels of other disciplines or objectives. An ecological threshold could lead to socio-economic disruption and have insufficient political acceptance to be ever achieved.

A good illustration of the reasons above is the apparent difficulties to implement the concept of maximum sustainable yield (MSY) of fish. Larkin (1977) wrote “an epitaph for the concept of maximum sustainable yield”, in which he reviewed the rise and fall of the concept. The theory stated that fishing only the harvestable surplus of a fish population guarantees ongoing fish yields. The application of this relatively simple concept in real life was complicated, because “natural systems are sufficiently diverse and complex that there is no single, simple recipe for harvesting that can be applied universally. When there is added in the complexity and variety of social, economic and political systems, the number of potential recipes is just too enormous to be easily summarized by simple dogma” (Larkin 1977). He finishes his epitaph with: “Like the hero of a western movie, MSY rode off in the range, caught the villains at their work and established order of a sort. But it’s now time for MSY to ride off into the sunset. The world today is too complex for the rough justice of a guy on a horse with a six-shooter. We urgently need the same kind of morality, but we also need much more sophistication”.

The foregoing leads to the conclusion that sustainable management is more sophisticated than a search for and implementation of thresholds. Management needs knowledge of cause–effect relationships and of socio-economic and environmental effects of policy measures in order to maximize the total amount of human, human-made, natural and social capital. Trade-offs have to be made between environmental, social and economic goals, being ultimately a societal choice between weak and strong sustainability.
Translating the considerations above to the context of transboundary river basins and their management requires analysis incorporating (preferably integrating) the following:

1. Specification of a river's natural capital in terms of its functioning for societal benefit as well as for itself and in terms of the processes, including the spatial and temporal characteristics of these processes, which underpin that functioning.
2. Specification of the economic activities in the catchment together with the costs and benefits associated with use of the river's natural capital.
3. Specification of the impact of economic activities on a river's natural capital.
4. Specification of the spatial and temporal distribution of activities, capitals and impacts reflecting the essentially unidirectional flow of water and matter from the catchment to the river's mouth.
5. Consideration of the institutional arrangement with its multitude of spatial contexts, statutory authorities and management objectives, as well as existing social views in the different riparian states indicating the range of acceptable trade-offs.

This paper focuses on the interactions between natural capital and its use (points 1 and 3) and thereby on the ecological–economic interactions. Institutional aspects are important for transboundary river management, but are not the focus of this paper.
Studies that have been carried out in parallel (Delft University of Technology and Institute for Environmental Studies 1996; Hoekstra and Baarse 1998) concentrate on points 2, 4 and 5. All together these studies contribute to the multidisciplinary research project "Sustainability and Environmental Quality in Transboundary River Basins" (SQR), which is a co-operation of the Faculty of Civil Engineering of the Delft University of Technology and the Institute for Environmental Studies at the Free University of Amsterdam. SQR develops a decision-making framework to facilitate integrated management of transboundary river basins for sustainable development (Delft University of Technology and Institute for Environmental Studies 1996).
Description and analysis of the above-mentioned interactions is needed to enable river managers to make informed decisions regarding trade-offs and to identify options for sustainable management. In the following section this interaction between human use and natural capital is elaborated for rivers.

Socio-economic use and ecological feedbacks in transboundary rivers

Present rivers are a product of their history. River floodplains have historically been favoured sites for human habitation because rivers provided a number of environmental goods and services. In Fig. 2 an overview is given of the main human interventions in Western European river basins. In pre-medieval times, a river provided water for domestic and agricultural use, fish, fertile soils and possibilities for transport and waste removal. Rivers also provided disservices, notably the risk that flooding posed to life and property. To maximize benefits from use of a river and to minimize risks associated with disservices, the structure of many rivers has been changed. Dykes offered protection to settlements from flooding, and permitted agricultural development on floodplains. Forests on the floodplain and in the watershed were cut to provide land for agricultural activities (Petts 1989). Canalization of the river and the building of weirs and dams improved navigation, captured the energy of river flows, allowed houses and agriculture to become established on the alluvial plains and reduced flood risks (Petts 1989).
The use of rivers to remove wastes (industrial and municipal) and surpluses (agricultural chemicals) has caused a decline in water quality. This started about 1750 with organic pollution due to rising population densities (Meybeck and Helmer 1989). Since the beginning of nineteenth century, water quality degraded further because of increased discharges of urban sewage, effluents from developing industrial centres and agricultural intensification. Abatement of most large industrial and urban discharges from point sources was achieved during the 1970s and 1980s (Meybeck and Helmer 1989). As a result, drastic reductions were observed for many pollutants. However, the abatement of compounds from diffuse sources was less successful. The costs and effort required for the abatement of non-point source pollution are generally much higher than those for point sources (Hoogeveen 1995).
Overuse of river goods and services as well as various changes to rivers triggered ecological feedbacks with subsequent effects on the supply of goods and services and thus on users (see examples in Fig. 2). The decline in multifunctionality of rivers has led to conflicts between users. For the River Rhine the main ecological impacts reported are changes in species composition, such as a decrease in species diversity and abundance (Wolff 1978; Friedrich and Müller 1984; Admiraal et al. 1993; Internationale Kommission zum Schutze des Rheins 1993; Tittizer and Krebs 1996), a loss of spatial differentiation of species along the length of the river (Friedrich and Müller 1984; Van der Velde and Van den Brink 1994; Statzner and Kohmann 1995), the extinction of anadromic fish (Wolff 1978; Lelek 1989) and the dominance of exotic, pollution- or disturbance-tolerant species (Van den Brink et al. 1991; Bij de Vaate 1993).
The main socio-economic sectors that have been impaired are:

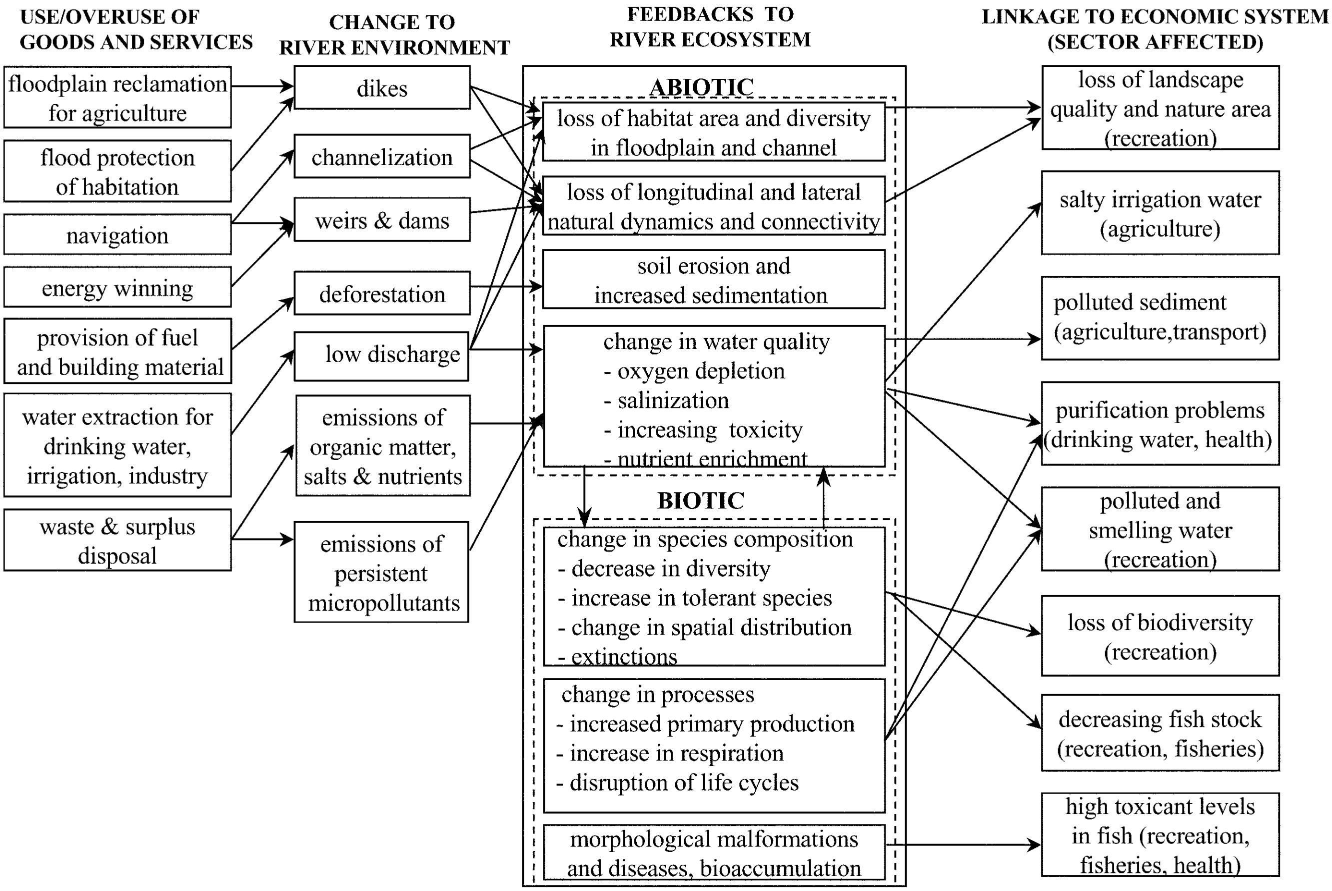

Fig. 2
Implications of using the predominant goods and services of rivers

1. Production of drinking water, due to traces of, e.g., polar pesticides, nitrate and toxic algae (Ietswaart and Van Dijk 1996; RIWA 1997).
2. Fisheries, because of decreases in stocks and diversity of species (Lelek 1989) and bio-accumulation of contaminants (De Boer and Hagel 1993; Internationale Kommission zum Schutze des Rheins 1993)
3. Recreation, due to a decline in recreational amenity involving poor water quality, loss of sport fish and changes in the river landscape.

The unidirectional flow of water and matter from the catchment to the river mouth results in the situation that a variety of upstream uses culminate into impacts on supply of downstream goods and services. The combination of multiple causes, spatial and temporal dynamics and the large spatial scale of river basins complicates specification of the relative contributions of any individual cause to any one effect. This hampers management, particularly since upstream users tend not to experience the negative effects of their actions. Moreover, river management depends on a large number of institutions, which defend only one sectorial (e.g. transport, agriculture, recreation, environment) or national interest in rivers. Management under these conditions may be dominated by particular interests, which can inhibit integrated management of a river. Such a situation can easily compromise the multifunctionality of rivers and expose them to the risk of irreversible change, thereby limiting future opportunities of use. The impacts of such changes on rivers and their functioning have led to pressures for ecological rehabilitation and more integrated management.

The Rhine Action Programme (RAP) of 1987, which focuses mainly on improvement to water quality, can be seen as a starting point for ecological rehabilitation. After the RAP began, the focus shifted to the hydrological and geomorphological aspects of ecological rehabilitation. The "Ecological Master Plan for the Rhine" was developed, which aims at the return of migratory fish and restoration of the connections between the river and its bordering riparian zones and floodplains (International Rhine Committee 1994; Van Dijk et al. 1995).

The ecological and environmental condition of the Rhine has improved considerably since its poor state during the 1970s. Almost all objectives for water quality, as set out in the RAP, have been achieved, except for a number of metals, organic micropollutants and nutrients (Internationale Kommission zum Schutze des Rheins 1993). The number of macro-invertebrate species is nearly the same as at the beginning of this century, but the present composition includes some exotic and generalist species that are more tolerant to changing environmental conditions (Internationale Kommission zum Schutze des Rheins 1996). Diversity and abundance of fish are improving, but they also comprise many generalist species. Rheophilic

and anadromic species are still rare in the Rhine, although there is probably a viable population of salmon (Internationale Kommission zum Schutze des Rheins 1997). Recent ecological rehabilitation projects and plans are combining river ecosystem restoration with other purposes, such as flood protection, exploitation of gravel and sand stores, recreation (Projectbureau Grensmaas 1994; Internationale Kommission zum Schutze des Rheins 1995; Ministerie voor Verkeer en Waterstaat 1996), filtering of diffuse pollution by riparian vegetation (Hammer 1992; Mitsch 1992) and water purification by wetlands (Rai et al. 1995; Vymazal 1996).
Simultaneously with the human use of rivers, management of river basins has developed from small-scale and single-sector to a more integrated approach on a catchment scale, including the coastal seas. Therefore concepts and tools are needed to analyse and describe economic, societal and environmental interests in order to make informed trade-offs and ensure that long-term aspects are considered as an integral part of the decision-making processes.

Concepts and tools for management

The framework within which interests can be traded-off should relate socio-economic use of the river's goods and services to the functioning of the river ecosystem and subsequent supply of goods and services on a catchment scale. The multidisciplinary research project "Sustainability and Environmental Quality in Transboundary River Basins" (SQR; Delft University of Technology and Institute for Environmental Studies 1996) is developing a decision-making framework to facilitate integrated management of transboundary river basins for sustainable development. In this section, a number of concepts and tools are described, which form the basis of the framework. In the next section, the concepts and tools are applied to a case study on nutrient abatement in the Rhine basin. The tools should provide information on the economic, ecological and social effects of different management alternatives. Figure 3 presents a picture of the role of each tool and concept in river basin management.
Firstly, indicators are a potentially suitable tool to summarize and communicate a large amount of information at the scale of the river basin. An indicator is defined in this paper as a variable or an aggregated set of variables giving information on a system, process or state, and which has significance beyond its face value. Indicators can steer data collection and provide a means of communication to policy makers and the public. In the case study a set of indicators has been developed to indicate the level of environmental quality after nutrient abatement (see Fig. 4).
Secondly, models provide a means for predicting the future condition of river basins, which is subject to natural variability, socio-economic developments and the implementation of policies, through scenario analysis. In the case study, a suite of economic, emission, water quality and ecosystem models has been used to evaluate management strategies of nutrient abatement (see Table 1). This suite of models attempts to capture the dynamics in space and time of the river with regard to its abiotic, ecological and economic characteristics. More information on the modelling can be found in Lorenz (1999).
Thirdly, the use of the suite of models for scenario analysis implies the development of an evaluation framework. In comparing the predicted effects of alternative management measures, insights can be gained into the possible trade-offs, and their acceptability, that are involved in river basin management. Management alternatives will be evaluated in a framework for sustainable management on the basis of three objectives (Gilbert et al. 1998):

1. Economic efficiency as lowest net costs at the catchment scale. An allocation of goods and services is said to be economically efficient when net benefits are maximized. If the costs of a policy objective are higher than their economic benefits, as is the case in our case study, a cost effectiveness analysis can be done as a proxy for economic efficiency. Cost effectiveness aims to reach an objective at least costs. It is an important dimension when evaluating sustainable development, since it provides a check on whether a certain policy objective has been achieved with a minimum of resource input.

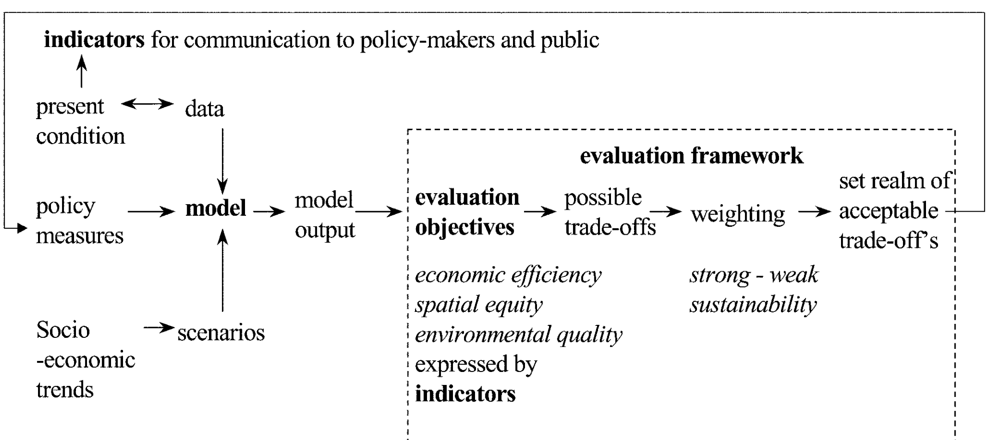

Fig. 3
Overview of the role and relationships of models, indicators and the evaluation framework in river basin management

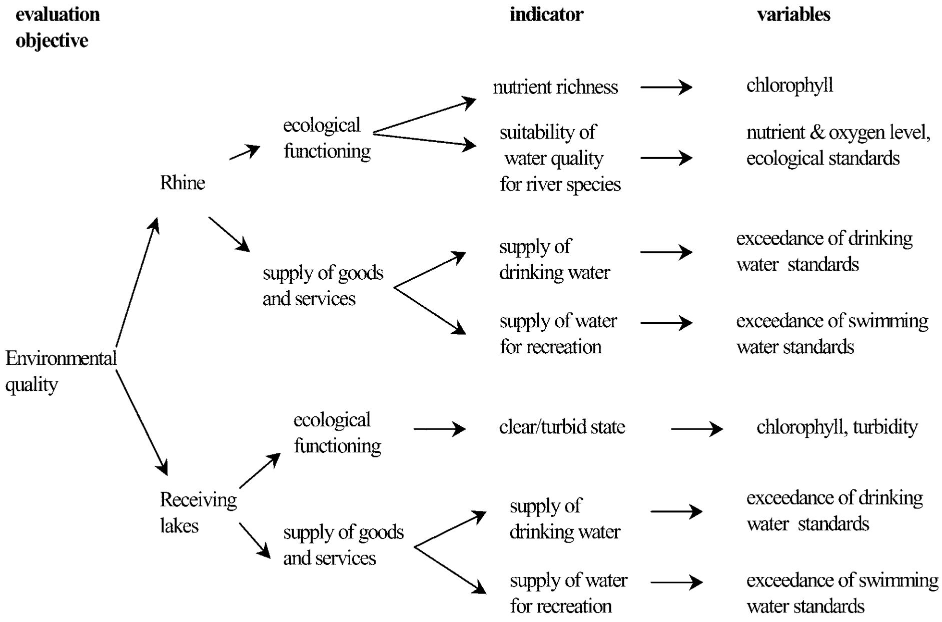

Fig. 4
Indicators that measure and assess the change in environmental quality in the River Rhine and receiving lakes after nutrient abatement

Table 1
Available models and data collected for calculation of the evaluation objectives

Model/database	Subject	Output variables
Nutrient emission database (De Wit 1999)	Nutrient emissions	Emissions of N and P based on land use and population densities
Transport model (Schuttelaar and Schmitz 1998)	Transport	Load of N and P into river
River water quality model DELWAQ (Schuttelaar and Schmitz 1998)	Water quality Algal concentrations Functional ecosystem processes	NO_3^-, NH_4^+, PO_4^{3-}, total N and P, O_2, organic N and P, Si, Secchi depth, chlorophyll-a concentration of diatoms and non-diatoms, primary production, respiration, (de)nitrification, mineralization, sedimentation, resuspension, mortality
Cost eectiveness model (Van der Veeren and Tol 1997)	Cost eective allocation of reduction measures	Costs are derived from Leneman (1992); benefits are estimated by Lise and Van der Veeren (in preparation)

2. Spatial equity: rivers often display an unequal distribution of space of the benefits and costs of their use. Upstream users have their opportunity to export the costs of their river use to downstream. Unequal distribution of the benefits and costs of emission reduction reduces the likelihood that riparian countries or regions will cooperate in reducing their emissions, and increases the likelihood of transboundary conflicts.
3. Environmental quality: this concept attempts to describe the potential of natural capital to contribute to human welfare through measuring the ecological functioning of the river both for its own benefit and in its capacity to supply environmental goods and services.

To describe ecological functioning, knowledge of the dominant ecosystem processes and characteristics of large rivers has been derived from river concepts (Lorenz et al. 1997). These theoretical concepts on the functioning of natural undisturbed river ecosystems provide the basis for describing and assessing the natural capital of rivers, e.g. River Continuum Concept (Vannote et al. 1980), Flood Pulse Concept (Junk et al. 1989), Catchment Hierarchy (Townsend 1996).
The goods and services that a river provides have been identified by using the concept of environmental functions (De Groot 1992; Gilbert and Janssen 1998). An environmental function is defined in this study as the set of ecological and physical processes behind the provision of an environmental good or service. We identified eight environmental functions (see Table 2). Environmental functions describe the interaction between the socio-economic system and the river by identifying environmental goods and services and the ecological processes behind their supply. As can be seen in Table 2, ecological processes support the supply of different goods and services. Furthermore, environmental functions specify the full range of environmental goods and services being used. Since the environment is an externality in conventional economic terms, environmental functions can provide the means for a more complete valuation of costs and benefits.

Table 2
Environmental functions of rivers, their supporting ecological processes and goods and services supplied

Ecological and physical processes	Environmental functions	Environmental good or service supplied
Catchment drainage and channel fall Discharge of water Erosion and sediment deposition in catchment and channel Topsoil formation Exchange of nutrients, minerals, etc. with riparian and other adjacent ecosystems Riparian and floodplain habitat formation and preservation Storage/recycling of organic matter, nutrients and wastes Fixation of solar energy and biomass production	Supply of water and water flows Supply of raw materials for construction, industrial and other purposes	Water, kinetic energy Wood, reed, sand, gravel, etc.
Discharge of water Fixation of solar energy and biomass production Topsoil formation in floodplain Storage/recycling of organic matter, nutrients, wastes and surpluses Exchange of nutrients, minerals, water, etc. with riparian and other adjacent ecosystems Riparian, floodplain and channel habitat formation and preservation Spawning and nursery habitat formation and preservation Migration of species within and between river(s)	Supply of food	Fish, shellfish, edible plants and fungi, medicinal resources, etc.
Catchment drainage and channel formation Erosion and sediment deposition in catchment and channel Exchange of water between river and other natural water reservoirs (e.g. groundwater, wetlands)	Regulation of water and sediment discharge	Flood mitigation Sediment stabilization
Discharge of water Fixation of solar energy and biomass production Storage/recycling of organic matter, nutrients and wastes Exchange of nutrients, minerals, etc. with riparian and other adjacent ecosystems Exchange of water between river and other natural water reservoirs (e.g. groundwater, wetlands)	Regulation of water quality	Assimilation of wastes via removal, storage, uptake and recycling (incl. waste disposal)
Discharge of water Fixation of solar energy and biomass production Storage/recycling of organic matter, nutrients and wastes Exchange of nutrients, minerals, etc. with riparian and other adjacent ecosystems Riparian, floodplain and channel habitat formation and preservation Spawning and nursery habitat formation and preservation Migration of species within and between river(s)	Maintenance of biological and genetic diversity	Genetic variation, species richness, diversity of ecosystems and landscapes
Catchment drainage and channel fall Discharge of water Erosion and sediment deposition in catchment and channel Topsoil formation	Provision of space or substrate for human activities	Space for transport (river and banks), recreation, fishing (river and banks), agriculture, human settlement and industry (floodplains)
All of the above	Provision of intrinsic, cultural, historical, educational and/or scientific values	Information, satisfaction, inspiration, sense of well-being

The above-mentioned tools and concepts have been applied in a case study. A summary of the case study will be given in the next section.

Case study: nutrient abatement in the Rhine basin

The case study involves the evaluation of four management strategies on nutrient abatement in the Rhine basin. The Rhine basin has a size of 185,000 km^2 and length of 1,320 km. The river basin lies in seven countries: Switzerland, Austria, Germany, France, Luxembourg, Belgium and The Netherlands. At present the population number in the whole basin is about 60 million people. The river discharge is very constant in space and time, because the Rhine is both rain- and snow-fed and the tributaries are evenly distributed over the main river channel (KHR 1993; Van Breukel 1993). The Rhine is one of the most intensively navigated rivers in the world with more than 150,000 ships and 180 million tonnes of goods passing the German–Dutch border each year (Huisman et al. 1998). Industry is concentrated along the Rhine, with the chemical companies Sandoz in Basel and BASF in Ludwigshafen. The heavy industry of the Ruhr area, the region with the

highest industrial concentration in Germany, discharges into the Rhine. Two large harbours lie along the Rhine: Rotterdam, one of the largest ports in the world, lies at the mouth of the Rhine, and Duisburg, the largest inland harbour of Europe, lies in the middle of the Ruhr area. These facts illustrate that the Rhine has been and still is of large economic importance.
The next section describes the management strategies. Then, the calculation method and results will be presented for each evaluation objective. Finally, the evaluation of the three objectives is described.

The management strategies

The case study involves the analysis of four management strategies. The policy measures in the management strategies are based on the Rhine Action Plan (Internationale Kommission zum Schutze des Rheins 1987) and North Sea Action Plan. The four strategies are (see Table 3):

1. The management strategy with policy aims for the year 1995. The Rhine Action Plan has the target of 50% emission reduction of nutrients by 1995. This reduction percentage will be calculated for emission reduction at the source level (strategy: 50%s:50% reduction of all sources).
2. Fifty percent emission reduction at the Rhine level (strategy: 50%R reduction of load into the Rhine). Reduction of load at the Rhine level allows for a cost-effective allocation of emission reduction measures in the sub-basins, and will lead to lower costs than the reduction at source level.
3. The management strategy with policy aims for the year 2000. The percentage emission reduction in the North Sea Action Plan is set at 70% for nitrogen and 75% for phosphorus, compared to the levels of 1985. This reduction percentage will be calculated for emissions at source (70%s).
4. Seventy percent for nitrogen and 75% for phosphorus reduction at the Rhine level (70%R).

The models presented in Table 1 and the indicators in Fig. 4 have been used to calculate the values of the evaluation objectives economic efficiency, spatial equity and environmental quality for each of the four management strategies, as will be explained in more detail in the next sections.

Cost effectiveness

For the calculation of the cost effectiveness, an economic optimization model is used that allows the design of the most cost-effective means of nutrient abatement for the whole catchment on the basis of the spatial distribution of the benefits and costs of emission reduction strategies (Lise and Van der Veeren (in preparation). Cost data were available for various nutrient abatement measures for a number of agricultural activities (Leneman 1992) and sewage and wastewater treatment plants (Baan 1991). Monetary benefits of nutrient abatement strategies are assumed to occur only in the downstream area. Here, drinking water purification plants using surface water as their main source might be able to reduce treatment activities and thus save on the application of chemicals (Van der Veeren and Rietveld 2000). Furthermore, recreational people may prefer clear water and will therefore appreciate their day trips more when eutrophication is reduced (Van der Veeren 1999).
Table 4 presents the result of the cost-effectiveness analysis, namely the net costs of the 50 and 70% emission reduction scenarios in the various regions, applied at source and at the level of the Rhine. Since eutrophicated Rhine-fed lakes are only located in The Netherlands, all recreational benefits are assumed to take place in this downstream country. If all turbid Rhine-fed lakes would become clear, the benefits for recreation in The Netherlands are a little over 4 million Euro/year. Furthermore, Dutch drinking water purification plants using surface water as their main source will be able to reduce the amounts of chemicals needed to purify the water. Their savings are 1,000 Euro/year in the 50% reduction cases, and 3,000 Euro/year in the 75/70% reduction cases (Van der Veeren and Rietveld 2000). When comparing costs and benefits of nutrient abatement in the Rhine basin, it appears that the costs outstrip the monetary benefits by far. Applying a reduction to emissions at source level appears to be much more expensive than reducing loads to the Rhine, since the latter policy leaves opportunities for the regions to allocate emission reduction in a cost-effective way. Some activities have more and cheaper opportunities to reduce nutrient emissions than other activities. For example, sewage treatment plants can reduce phosphorus loads relatively cheaply, compared to agriculture. The relative shares of the various activities in a particular region determine whether that region will be able to benefit from a reallocation of nutrient reduction measures.

Spatial equity

The Lorenz curve and the Gini coefficient are useful concepts to describe spatial equity of the scenarios in the Rhine river basin. They are normally used to describe income distribution (Heijman et al. 1988), but they can also be applied to measure the spatial distribution of costs and benefits of nutrient abatement. For this purpose, net costs per region have been divided by the number of people within those regions (see Table 4). The regions were then ordered according to their net costs per capita. After expressing the number of people living in the various regions as a percentage of the total population in the Rhine River basin, and the total net costs per region as a percentage of total net costs in the Rhine River basin, a Lorenz curve (Fig. 5) can be made. If the net costs per capita are equal for all regions, the curve would coincide with the

Table 3
Scenarios of nutrient emission reduction at source (*s*) or into the Rhine (*R*), based on International Rhine Committee (IRC) plans (Internationale Kommission zum Schutze des Rheins 1987)

Scenario	IRC plan	Emissions of N and P
50%s/R	Policy aim of 1995	50% N and P reduction
70%s/R	Policy aim of 2000	70% N and 75% P reduction

diagonal. The closer the curve lies to the diagonal, the more equal the distribution is. The inequality of the distribution is expressed by the Gini coefficient (Heijman et al. 1988), having a value of 0 in a complete equal situation and a value of 1 in a complete unequal situation. The Gini coefficient is calculated by dividing the surface between the curve and the diagonal by the surface under the diagonal.

It should be noted that the Gini coefficient in this case study expresses the (in)equality of net costs per capita of the rehabilitation measures proposed and not the absolute equality in costs and benefits per region or per capita of river use. So, it measures the 'marginal' equality, namely the equality of change. Marginal equality says nothing about absolute equality. It could even be the case that an unequal marginal equality leads to a higher absolute equality or vice versa. However, no absolute costs and benefits are available in this study; therefore the absolute equality cannot be determined and the marginal equality will be used instead. The marginal equality of rehabilitation measures indicates the feasibility of reaching an international agreement. If the costs are very unequally distributed, the feasibility will be lower.

Figure 5 presents a Lorenz curve and Table 5 presents the Gini coefficient for the spatial distribution of total net costs for the rehabilitation scenarios. This figure and table show that the two reduction at source policies, which coincide almost completely, result in a more unequal distribution of net costs over the inhabitants of the various regions. This may seem counterintuitive at first glance. However, due to the relatively high costs of nutrient abatement by agricultural activities compared to sewage treatment plants (especially with respect to phosphorus emission reduction), the sewage treatment plants will be required to reduce emissions to a larger extent when nutrient emission reductions are allocated in a cost-effective way. Since the number of sewage treatment plants is related to the number of inhabitants, this means that costs of nutrient abatement by sewage treatment plants are

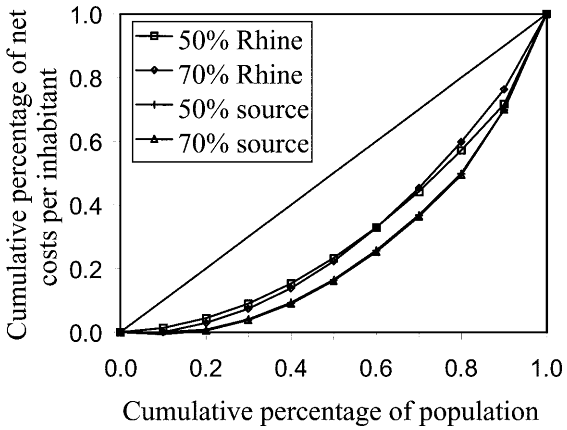

Fig. 5
Lorenz curves for the distribution of total net costs of river rehabilitation over the population inhabiting the Rhine basin. *Curves* measure extent to which different regions in the Rhine basin bear the net costs. Note that the 50% source curve coincides with the 70% source curve. *Diagonal line* represents equal costs per inhabitant. *Other lines* represent spatial distribution under different abatement scenarios

Table 5
Gini coefficients and spatial equity value per rehabilitation scenario

Scenario	Gini coecient	Spatial equity (1–Gini)
50% Rhine	0.396	0.604
50% Source	0.508	0.492
70% Rhine	0.386	0.614
70% Source	0.514	0.486

Table 4
Net costs per region (million Euro/year) and per person in that region (Euro/year) of 50 and 70% nutrient emission reduction applied at source (*s*) or into the Rhine (*R*) for various regions in the Rhine River basin

Region	Scenario							
	50%s (per region)	50%s (per region)	70%s (per region)	70%s (per region)	50%R (per region)	50%R (per person)	70%R (per region)	70%R (per person)
Switzerland	490	97	1,037	205	125	25	254	50
Austria	14	3	31	6	5	1	11	2
France	491	97	1,089	215	76	15	160	32
Luxembourg	57	11	125	25	10	2	22	4
Belgium	8	2	18	4	2	0	4	1
Thuringen	12	2	27	5	1	0	3	1
Nordrhein-Westfalen	623	123	1,292	255	175	35	354	70
Hessen	233	46	499	99	59	12	123	24
Rheinland-Pfalz	324	64	702	139	62	12	127	25
Baden-Wurttemberg	604	119	1,293	256	136	27	281	56
Saarland	37	7	80	16	12	2	25	5
Bayern	523	103	1,134	224	39	8	78	15
The Netherlands	822	162	1,700	336	245	48	575	114
Total	4,238	64	9,027	137	948	14	2,019	31

also related to the number of inhabitants. The more nutrient abatement takes place at sewage treatment plants, the more equal the distribution of the total nutrient abatement costs over the population becomes and thus the costs per capita. Or, to put it the opposite way, in a flat rate emission reduction policy, the costs of nutrient abatement by agricultural sources will be higher, since sewage treatment plants will reduce their emissions to a lesser extent than in a cost-effective allocation. These costs for agricultural nutrient abatement will then be a larger proportion of the total nutrient abatement costs. Since the size of the agricultural activities in the Rhine basin is not necessarily related to the number of inhabitants, the abatement costs per capita will be less equally distributed than in a cost-effective allocation of nutrient abatement measures.

Environmental quality

The environmental quality component consists of a number of simulation models, which describe emissions from the catchment into the river, their subsequent transport and processing, and the resulting water quality and ecological condition in the river and receiving lakes. Indicators translate the model output into information on the change in environmental quality after nutrient abatement (Lorenz 1999). The indicators are presented in Fig. 4. The assessment of the indicator values occurs by comparing the year maximum value of water quality parameters with environmental standards. If the standard is met, the evaluation value is 1, if the standard is not met, the value is 0. The assessment is different for ecological functioning of lakes; if the lake is in a mesotrophic and clear condition, the value is 1, and if the lake is eutrophic and turbid, the value becomes 0.

The assessment values have to be aggregated into one number. For the evaluation of environmental quality, the individual indicator values are aggregated into values of ecological functioning and the supply of goods and services, and then into environmental quality (see levels in Fig. 4). The next step is to aggregate the environmental quality values of each river section into one value for the total Rhine on the basis of the relative length of each section. Finally, the environmental quality values for the Rhine and lakes are aggregated. In this case study, an equal weighting factor has been applied in each aggregation step. Table 6 presents the environmental quality values per river section for the whole Rhine and for the lakes for the management strategies. The environmental quality increases with more nutrient abatement and decreases from up- to downstream. The differences in indicator values between emission reduction at source (50 and 70%s) and into the Rhine (50 and 70%R) are negligible (see environmental quality values in Table 7). Therefore, only the results of emission reduction into the Rhine will be shown in Table 6.

Evaluation of the management strategies on the three objectives

Techniques derived from multi-criteria analysis were used to analyse trade-offs between evaluation objectives and to derive a ranking of management strategies. These techniques are implemented in the software package DEFINITE (Janssen and Van Herwijnen 1993).

The management strategy with the highest total value is the most preferred (compare with the sustainability rule of the total sum of the four capitals). Therefore, the values of the evaluation objectives have to be added up to evaluate the management strategies. In order to add up values with different units, the objectives cost effectiveness, spatial equity and environmental quality are standardized between 0 and 1, multiplied by a weighting factor and added together. Summation of the standardized values with equal weighting leads to the numbers listed in Table 7. According to this table, a 70% emission reduction into the Rhine would be the most preferred scenario, before 50% into the Rhine, 70% at source and

Table 6
Environmental quality values per river section and for the whole Rhine for the scenarios

Scenario	River sections of the Rhine	Algae	Nutrients	Ecological functioning	Drinking water	Recreation	Supply of goods and services	Environmental quality
50%	HR[a]	1	0	0.5	1	1	1	0.75
	SOR	1	0	0.5	1	1	1	0.75
	NOR	1	0	0.5	1	1	1	0.75
	MR	1	0	0.5	1	1	1	0.75
	NR	1	0	0.5	1	1	1	0.75
	DR	1	0	0.5	0	1	0.5	0.5
	Rhine	1	0	0.5	0.87	1	0.94	0.72
	Lake	0	1	0.5	0.88	0.5	0.7	0.6
	Total	0.5	0.5	0.5	0.88	0.75	0.82	0.66
70/75%	HR	1	1	1	1	1	1	1
	SOR	1	1	1	1	1	1	1
	NOR	1	1	1	1	1	1	1
	MR	1	0	0.5	1	1	1	0.75
	NR	1	0	0.5	1	1	1	0.75
	DR	1	0	0.5	0	1	0.5	0.5
	Rhine	1	0.53	0.77	0.9	1	0.94	0.85
	Lake	1	1	1	0.94	0.75	0.85	0.93
	Total	1	0.77	0.89	0.92	0.88	0.90	0.89

[a]HR, Hochrhein; SOR, Suedlicher Oberrhein; NOR, Noerdlicher Oberrhein; MR, Mittelrhein; NR: Niederrhein; DR, Deltarijn

Table 7
Standardized values of the evaluation objectives and total value aggregated by an equal weighted summation per scenario

Scenario	Least net costs	Spatial equity	Environmental quality	Total value
50% Source	0.59	0.00	0.05	0.64
50% Rhine	1.00	0.92	0.00	1.17
70% Source	0.00	0.00	1.00	1.00
70% Rhine	0.87	1.00	0.95	1.82

the 50% at source emission reduction policy. Assigning different weights to the objectives can reverse the ranking of scenarios.

The summation of standardized values does not clearly show the relationship between the evaluation objectives; therefore two-dimensional scatter diagrams are used (Janssen and Padilla 1996). The scatter diagrams are derived from DEFINITE. A three-dimensional figure is perhaps more appropriate but less transparent. The point of using these diagrams is to show to readers (and, in special cases, decision-makers) the implications of the weights or preferences that they assign to the objectives.

The plotting of aggregate values of evaluation objectives in scatter diagrams, as presented in Fig. 6, also requires aggregation of indicators into one measure and relative scaling between 0 and 1 for each evaluation objective. The correlation coefficient shows the extent of agreement (positive value) or conflict (negative) between objectives. The objectives could be plotted in a three-dimensional figure, but the advantage of the two-dimensional plot is its high transparency. The scatter diagrams confront policy makers with the consequences of their decisions and preferences through the chosen weights for the objectives. The scatter plots demonstrate that spatial equity and efficiency are in conflict with environmental quality, but not with each other. This can also be illustrated by the signs of the correlation coefficients. The very small correlation coefficient for spatial equity versus environmental quality represents the fact that there is no significant relation between these two objectives. Furthermore, it appears that a shift from at-source emission reduction policies to a more cost-effective allocation (e.g. restriction on the loads to the Rhine) has no significant impact on environmental quality, but leads to different costs and a different spatial distribution.

Conclusions and discussion

This paper identified a line of reasoning and derived on that basis a number of concepts and tools to facilitate river basin management, which have been applied in a case study. For long-term sustainable river basin management a balance is needed between the human use of the river and its basin, ecological functioning of the river and receiving waters, and the river's capacity to supply goods and services. To find such a balance a framework is needed that illustrates and clarifies possible trade-offs between economic use and environmental supply by integrating scientific information on cause–effect chains on a catchment scale.

A number of concepts and tools are proposed as a basis for this framework. The tools are: (1) indicators that describe the complex interactions and processes in rivers; (2) a suite of linked models, that predict the economic, environmental and ecological effects of management measures; (3) an evaluation framework to rank different management alternatives on the basis of three objectives: economic efficiency, spatial equity and environmental quality. The concept of environmental quality defines the potential of the river environment (i.e. natural capital) to contribute to human welfare. The concept of environmental functions is used to identify societal interest in natural capital.

This paper focuses on the interactions between the socio-economic use of the river and ecological functioning. Institutional aspects are not the subject of this study. However, the approach and results of this study have some implications for the institutional aspects of transboundary river management. In their theses, Dieperink (1997) and Meijerink (1998) analysed the process of decision-making at an international scale for respectively the Western European Rhine and Schelde basins, and concluded that scientific knowledge influences the decision-making in transboundary river basins in different ways. In the following paragraphs we compare the role of scientific knowledge in decision-making with the study presented in this paper, namely the applied concepts and tools and results of the case study.

In the first place, Dieperink (1997) and Meijerink (1998) argue that research that produces new knowledge on the intellectual relationships in an issue influences the perceptions of the actors involved in decision-making on that issue and consequently their objectives and strategies. These intellectual relationships may offer new opportunities to come to compromises, deals and agreements between different governments. The integration of scientific knowledge of different disciplines in one management-oriented study, as presented in this case study, helps to reveal new intellectual relationships. For example, the finding that reduction at source, as agreed upon in the Rhine Action Plan, leads to higher costs but a more equal distribution of costs among the regions. Reduction of loads allows a more cost-effective strategy. The unequal distribution of costs can be reduced by applying side payments between regions.

Secondly, scientific knowledge can reduce the uncertainty of governments with regard to their problem perception and strategy (Dieperink 1997). A high uncertainty will reduce the willingness of governments to make decisions. The combination of concepts and tools gives information on the ecological and economic effects of management

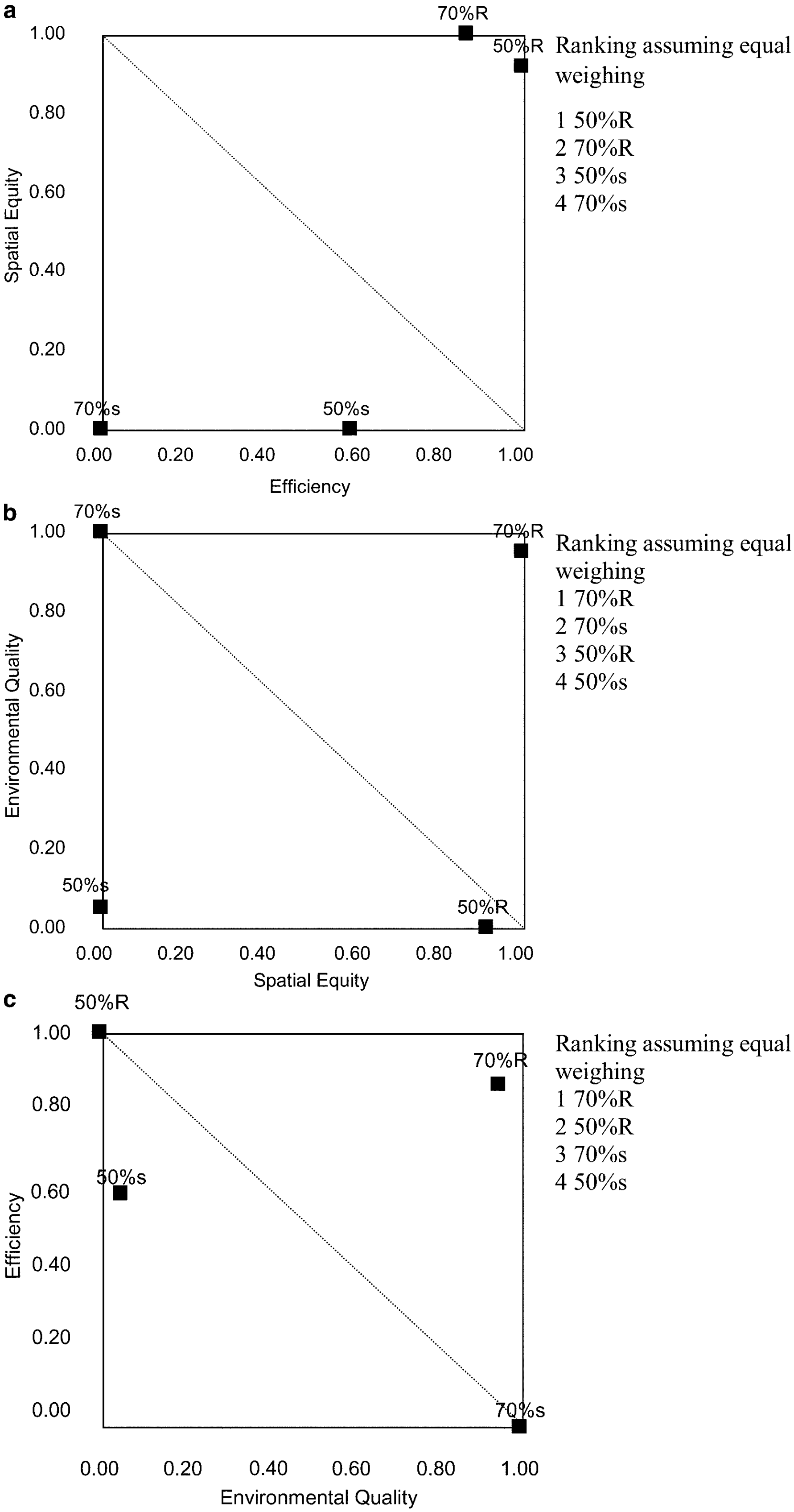

Fig. 6
Scatter plots comparing the evaluation objectives for the four management strategies: cost effectiveness (efficiency) versus spatial equity, spatial equity versus environmental quality and environmental quality versus cost effectiveness

strategies and measures over space and time. It allows a search for the most economic-efficient and ecologically effective measures in the river basin.

Thirdly, one way to tackle downstream pollution is to financially compensate the upstream states for emission reduction. An economic analysis of the costs and benefits of emission and emission reduction, as carried out in this case study, can be the basis for the amount of compensation. Financial compensation is, however, still controversial, because it is in conflict with the polluter pays principle and the precautionary principle (Meijerink 1998).

Finally, according to Dieprink (1997), a river basin organization, such as the International Rhine Commission or the International Commission for the Protection of the Scheldt, operates more successfully when it has a strategic vision. The strategic vision should be a challenge for the basin states, should be sufficiently concrete and have advantages for all participants. The objectives of the strategic vision should be measurable. This paper presents a line of reasoning on sustainable management of transboundary rivers. The presented framework enables the identification of measures to achieve the three measurable objectives in order to achieve sustainable management.

In conclusion, quantitative information on cause–effect relationships and on economic and environmental effects of both the present situation and under different management strategies may help to achieve international agreement on strategies, including interventions, investments and burden sharing. Political and legal action can be based on quantitative and transparent information, and economic instruments (e.g. side payments) can be applied more effectively. Specification of weights and objectives will increase the transparency in decisions about transboundary river basin management. This transparency is a necessary condition for effective public participation, a key issue in integrated water management and sustainable development.

It is clear to the authors that this paper focuses on the Western European situation. For environmental issues such as transboundary pollution, environmental awareness and economic prosperity are important background variables. Environmental awareness increases the willingness to invest in environmental policies, and economic prosperity enables the parties to allocate financial resources for such investments. Furthermore, in Western European river basins political cooperation is already established through supranational organizations, such as the European Union. These boundary conditions for transboundary river management do not exist in large parts of the world. In the Middle East shortage of clean fresh water causes conflicts concerning water use. This conflict comes on top of other existing conflicts (e.g. land ownership, religion) in this region. However, the cause of the water shortage is comparable to transboundary problems in Western Europe, namely the overuse of water in the upstream regions. We think that transboundary cooperation and agreements in these regions will also be the only way to tackle transboundary problems in a sustainable way.

Acknowledgements We want to thank Marleen Schmitz for the modelling, Rob van der Veeren for the provision of the economic data, Nico van Straalen and Wim Cofino and the SQR project members for their comments, in particular Prof. Eelco van Beek, Prof. Harmen Verbruggen, Gerrit Baarse, Marlies Schuttelaar and Arjen Hoekstra. We also acknowledge the many comments, criticisms and suggestions of the four reviewers of this paper.

References

Admiraal W, van der Velde G, Smit H, Cazemier WG (1993) The rivers Rhine and Meuse in The Netherlands: present state and signs for ecological recovery. Hydrobiologia 265:97–128

Baan PJ (1991) Analyse van emissies door huishoudens en emissies via het riool naar het oppervlaktewater en de Noordzee. EC 167, Waterloopkundig Laboratorium, Delft

Bij de Vaate A (1993) Exotic aquatic macroinvertebrates in the Dutch part of the River Rhine: causes and effects. In: van Dijk GM, Marteijn ECL (eds) Ecological rehabilitation of the River Rhine. The Netherlands research summary report (1988–1992). Report of the project Ecological Rehabilitation of the Rivers Rhine and Meuse, no 50, pp 27–30

Braat L (1992) Sustainable multiple use of forest ecosystems: an economic–ecological analysis for forest management in The Netherlands. PhD Thesis, Vrije Universiteit, Amsterdam

Cole HSD, Freeman C, Jahoda M, Pavitt KRL (1973) Models of doom: a critique of the limits to growth. Universe Books, New York

Commission of the European Communities (2000) Communication on the precautionary principle. Commission of the European Communities, Brussels

Daly H (1974) The economics of steady state. Am Econ Rev 64:15–21

De Boer J, Hagel P (1993) Spatial differences and temporal trends of chlorobiphenyls in yellow eel (*Anguilla anguilla*) from inland waters of The Netherlands. Sci Total Environ 141:155–174

De Groot R (1992) Functions of nature: evaluation of nature in environmental planning, management and decision making. Wolters-Noordhoff, Groningen

Delft University of Technology, Institute for Environmental Studies (1996) Sustainability and environmental quality in transboundary river basins. Outline of a six-year research program. Delft University of Technology and Institute for Environmental Studies, Vrije Universiteit, Amsterdam

De Wit M (1999) Nitrogen and phosphorus emissions in the Rhine basin. Thesis, Utrecht University

Dieperink C (1997) Between salt and salmon. Lessons from the development of the regime concerning Rhine pollution (with a summary in English). Thesis, Utrecht University

Freestone D, Hey E (eds) (1996) The precautionary principle and international law. The challenge of implementation. Kluwer, The Hague

Friedrich G, Müller V (1984) Rhine. In: Whitton BA (ed) Ecology of European rivers. Blackwell, Oxford, pp 265–315

Gilbert AJ, Janssen R (1998) Use of environmental functions to communicate the values of a mangrove ecosystem under different management regimes. Ecol Econ 25:323–346

Gilbert AJ, Van der Veeren RJHM, Lorenz CM (1998) Trading economics for ecology? An integrated analysis of nutrient emissions in a transboundary river basin. Institute for Environmental Studies, Vrije Universiteit, Amsterdam

Hammer DA (1992) Designing constructed wetland systems to treat agricultural nonpoint source pollution. Ecol Eng 1:49–72

Hartwick JM (1977) Intergenerational equity and the investing of rents forum on exhaustible resources. Am Econ Rev 67:972–974

Heijman WJM, Van Ierland EC, Kroese EP, Oskam EA (1988) Leerboek van de algemene economie: macro-economie.

H.E. Stenfert Kroese Wetenschappelijke en educatieve uitgevers, Leiden
Hoekstra AY, Baarse G (1998) Managing diffuse emissions of nutrients in the Rhine basin. Intermediate report of the research project 'Sustainability and Environmental Quality in Transboundary River Basins'. Delft University of Technology and Institute for Environmental Studies, Vrije Universiteit, Amsterdam
Hoogeveen PMTC (1995) Results of the water quality research in the Dutch part of the Rhine, 1974–1993. RIZA Rep 95.010, Institute for Inland Water Management and Waste Water Treatment, Lelystad
Huisman P, De Jong J, Wisrika K (1998) Transboundary cooperation in shared river basins. Experiences from Rhine, Meuse and North Sea. In: Savenije H, Van der Zaag P (eds) Management of shared river basins. Ministry of Foreign Affairs, Den Haag, Nederland
Ietswaart T, Van Dijk GM (1996) Effects of eutrophication and hydrology on phytoplankton in the River Meuse. Consequences for drinking water preparation. RIVM Rep 733008002, National Institute for Public Health and the Environment, Bilthoven
Internationale Kommission zum Schutze des Rheins (1987) Aktionsprogramm Rhein. IKSR, Koblenz
Internationale Kommission zum Schutze des Rheins (1993) Statusbericht Rhein. IKSR, Koblenz
Internationale Kommission zum Schutze des Rheins (1995) Grundlagen und Strategie zum Aktionsplan Hochwasser. IKSR, Koblenz
Internationale Kommission zum Schutze des Rheins (1996) Das Macrozoobenthos des Rheins 1990–1995. IKSR, Koblenz
Internationale Kommission zum Schutze des Rheins (1997) Bestandsaufnahme der Rheinfishfauna 1995. IKSR, Koblenz
International Rhine Committee (1994) Salmon 2000.IRC, Koblenz
Janssen R, Van Herwijnen M (1993) DEFINITE, a system to support decisions on a finite set of alternatives. Kluwer, Dordrecht
Janssen R, Padilla PE (1996) Valuation and evaluation of management alternatives for the Pagbilao Mangrove. Creed working paper series. International Institute for Environment and Development, London, and Institute for Environmental Studies, Vrije Universiteit, Amsterdam
Junk JW, Bayley PB, Sparks RE (1989) The flood pulse concept in river-floodplain systems. In: Dodge DP (ed) Proc Int Large River Symp, Can Spec Publ Fish Aquat Sci 106:110–127
KHR (1993) Der Rhein unter Auswirkung des Menschen – Ausbau, Schiffahrt, Wasserwirtschaft. Internationale Komission fuer die Hydrologie des Rheingebietes, Bericht nr I-11, Lelystad, Nederland
Larkin PA (1977) An epitaph for the concept of maximum sustainable yield. Trans Am Fish Soc 106(1):1–11
Lelek A (1989) The Rhine River and some of its tributaries under human impact in the last two centuries. In: Dodge DP (ed) Proc Int Large River Symp, Can Spec Publ Fish Aquat Sci 106:469–487
Leneman H (1992) Kosten van reduktie van stikstof en fosforemissie op landbouwbedrijven. Vakgroep Agrarische Bedrijfseconomie, Landbouwuniversiteit Wageningen
Lorenz CM (1999) Indicators for sustainable management of rivers. Thesis, Vrije Universiteit, Amsterdam
Lorenz CM, Van Dijk GM, Van Hattum AGM, Cofino WP (1997) Concepts in river ecology: implications for indicator development. Reg Riv 13:501–516
Meadows DH, Meadows DL, Randers J, Behrens WW (1972) The limits to growth, a report for the Club of Rome project on the predicament of mankind. Universe, New York
Meijerink SV (1998) Conflict and cooperation on the Scheldt basin. Thesis, Delft University of Technology
Meybeck M, Helmer R (1989) The quality of rivers: from pristine stage to global pollution. Paleogeogr Paleoclimatol Paleoecol (Global and Planet Change Sect) 75:283–309
Ministerie voor Verkeer en Waterstaat (1996) Integrale verkenning inrichting Rijntakken. Ministerie voor Verkeer en Waterstaat, Den Haag
Mitsch WJ (1992) Landscape design and the role of created, restored and natural riparian wetlands in controlling nonpoint source pollution. Ecol Eng 1:27–47
Pearce DW, Turner RK (1990) Economics of natural resources and the environment. Harvester Wheatshead, Hemel Hampstead, New York
Petts GE (1989) Historical analysis of fluvial hydrosystems. In: Petts G, Möller H, Roux AL (eds) Historical change of large alluvial rivers: Western Europe. Wiley, Chichester, pp 1–18
Projectbureau Grensmaas (1994) Een mooie ruil. Projectbureau Grensmaas, Maastricht
Rai UN, Sinha S, Tripathi RD, Chandra P (1995) Wastewater treatability potential of some aquatic macrophytes: removal of heavy metals. Ecol Eng 5:5–12
RIWA (1997) Jaarverslag 1997. RIWA, Amsterdam
Schuttelaar MEJF, Schmitz MEM (1998) Modeling the effect of nutrient emission reductions on algae growth in the Rhine. In: Proc Man and Riversystem Conf, 25–27 Mar, Paris
Serageldin I, Steer A (1994) Epilogue: expanding the capital stock. In: Serageldin I, Steer A (eds) Making development sustainable: from concepts to actions. Environmentally Sustainable Development Occasional Paper Series no 2, World Bank, Washington, DC, pp 30–32
Solow RM (1974) The economics of resources or the resources of economics. Am Econ Rev 64:1–14
Statzner B, Kohmann F (1995) River and stream ecosystems in Austria, Germany and Switzerland. In: Cushing CE, Cummins KW, Minshall GW (eds) River and stream ecosystems. Ecosystems of the world 22. Elsevier, Amsterdam, pp 439–478
Tittizer T, Krebs F (eds) (1996) Oekosystemforschung Der Rhein und seine Auen – eine Bilanz. Springer, Berlin Heidelberg New York
Townsend CR (1996) Concepts in river ecology: pattern and process in the catchment hierarchy. Algol Stud 113:3–24
Turner KR, Pearce D, Bateman I (1993) Environmental economics: an elementary introduction. Harvester Wheatsheaf, Hemel Hampstead, New York
Van Breukel RMA (1993) De Rijn en Rijntakken, verleden, heden en toekomat. RIZA nota 93.004. Rijksinstituut voor Zoetwater en Afvalwaterzuivering. Lelystad, Nederland, Februari 1995, 92 pp
Van den Brink FWB, Van der Velde G, Bij de Vaate A (1991) Amphipod invasion on the Rhine. Nature 352:576
Van der Veeren RJHM (1999) Clear water in a natural swimming pool: The value of a less eutrophicated Zwemlust. Institute for Environmental Studies, Vrije Universiteit, Amsterdam
Van der Veeren RJHM, Rietveld LC (2000) The impact of reduced nutrient loads in the Rhine on the drinking water purification plant of Andijk. Institute for Environmental Studies, Vrije Universiteit, Amsterdam
Van der Veeren RJHM, Tol RSJ (1997) Cost-effective nutrient emission reduction strategies: building the data set. Working paper 97/2, Institute for Environmental Studies, Vrije Universiteit, Amsterdam
Van der Veeren RJHM, Tol RSJ (2000) Benefits of a reallocation of nitrate emission reductions in the Rhine River basin. Environ Resour Econ 18(1):19–41
Van der Velde G, Van den Brink FWB (1994) Does the Rhine still have characteristics of a river ecosystem? The longitudinal distribution of macroinvertebrates. Water Sci Technol 29:1–8

Van Dijk GM, Marteijn ECL, Schulte-Wülwer-Leidig A (1995) Ecological rehabilitation of the River Rhine: plans, progress and perspectives. Reg Riv 11:377–388

Vannote RL, Minshall GW, Cummins KW, Sedel JR, Cushing CE (1980) The river continuum concept. Can J Fish Aquat Sci 37:130–137

Van Rooy PTJC, De Jong J (1995) Op weg naar totaal waterbeheer. H_2O 28:62–66

Verbruggen H (1995) Mondiale duurzame ontwikkeling: efficientie en verdeling. Maandschr Econ 59:280–297

Vymazal J (1996) The use of subsurface-flow constructed wetlands for wastewater treatment in the Czech Republic. Ecol Eng 7:1–14

World Commission on Environment and Development (1987) Our common future. Oxford University Press, Oxford

Wolff WJ (1978) The degradation of ecosystems in the Rhine. In: Holdgate MW, Woodman MJ (eds) The breakdown and restoration of ecosystems. Plenum Press, New York, pp 169–187